Stopping of protons in pA collisions at SPS and NICA energies in analytical hydrodynamic model and in SMASH event generator

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Motivation of this study

STOPPING

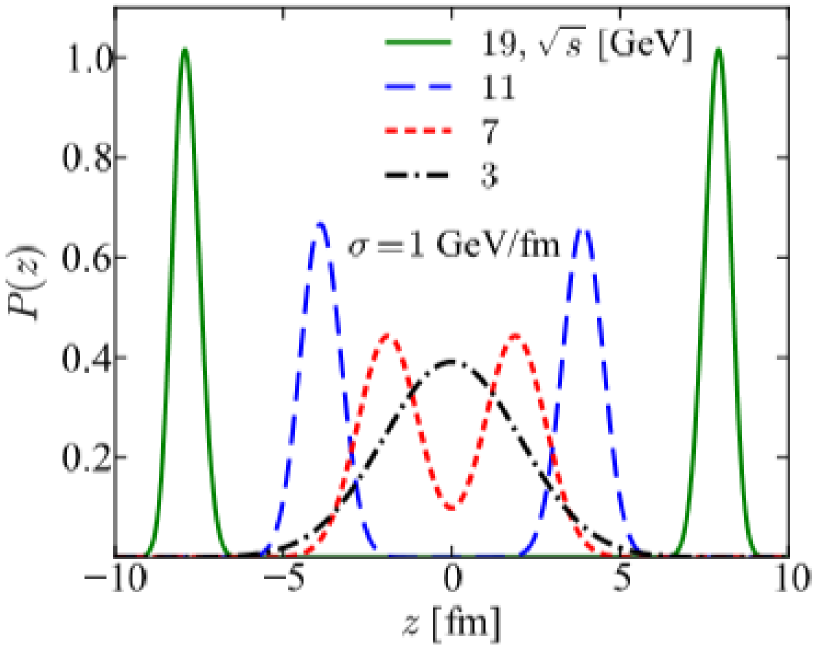


Fig.1. Stopped nucleons in configuration space [1]

[1] Andrzej Bialas, Adam Bzdak, Volker Koch (2016)

Non-Linear relationship[2]

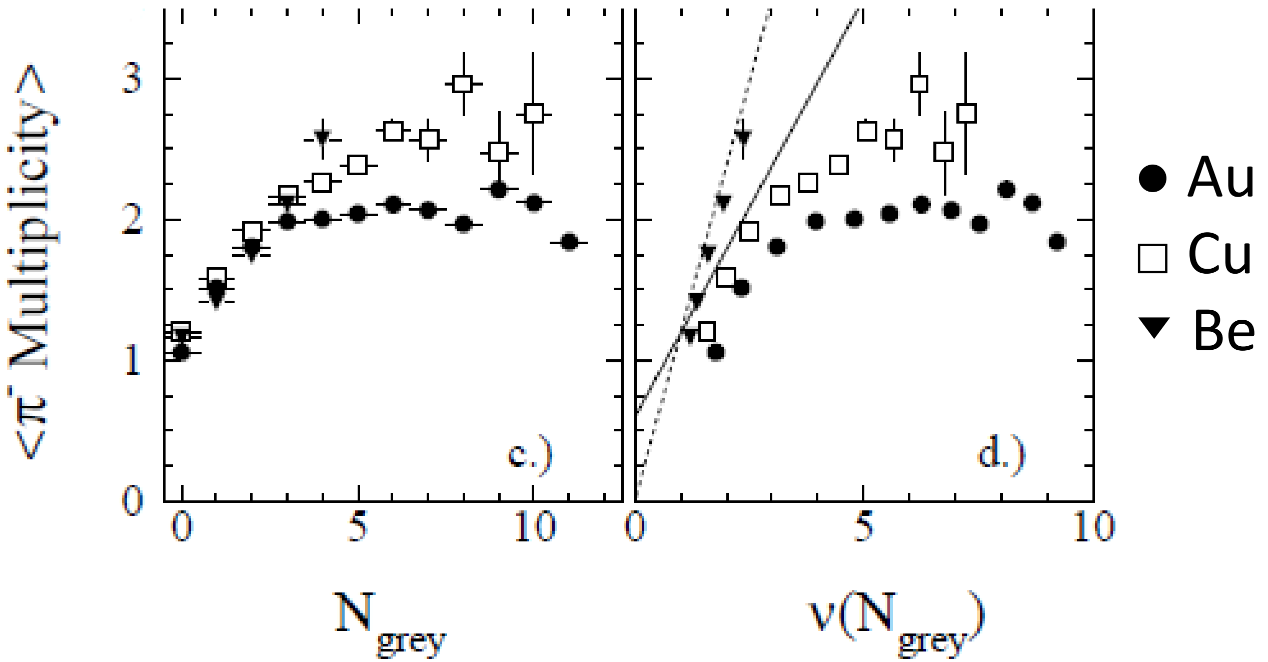


Fig.2. Multiplicity vs. number of "grey nucleons" (N_{grey}) and number of binary collisions ($\nu(N_{grey})$) in p-A collisions at 18 GeV/c[2]

[2] I. Chemakin et al. (1999)

Our hydrodynamic model of proton stopping

[3]L. Landau, E. Lifshits (1986)

- $dF^i = T^{ik} df_k; \quad T^{\alpha\beta} = \begin{pmatrix} \varepsilon & 0 & 0 & 0 \\ 0 & p & 0 & 0 \\ 0 & 0 & p & 0 \\ 0 & 0 & 0 & p \end{pmatrix};$ $\quad \varepsilon = \frac{M}{V}, \quad p = 0 \qquad T^{ik} = \frac{\varepsilon v^i v^k}{1 - v^2} \Rightarrow \quad F = -\frac{1}{1 - v^2} \varepsilon v^2 S$

- Known quantities: $v_0, \ \rho(r), \ \sigma_{inel}^{NN}$

  $m\vec{a}\gamma + m\vec{v}(\vec{v}\vec{a})\gamma^3 = \vec{F} \Rightarrow v(t)$

  Speed of the «stop» V_0 (when become gray) $\Big\} \Rightarrow l$

$$\frac{dv}{dt} = (-1)\frac{\varepsilon S}{m_{0p}} * v^2\gamma(1 + v^2\gamma^2)^{-1}$$

$$Const = (-1)\frac{\varepsilon S}{m_{0p}}$$

- Quantities used for calculation (p-Au - collision):

R, fm	a, fm	A	V_0	σ_{inel}^{NN}, fm^2	r_p, fm	m_{0p}, GeV	M, GeV	$p_{lab}, GeV/c$
7.64	0.538	197	0.5	2.85	1.2	1	197.09	18

- $Const \approx 0.1$ GeV

Glauber-like approach:

[4] Cheuk-Yin Wong (1994)

- $$T(b) = \iint_{\Omega} \rho(z, \boldsymbol{b_A}) \delta(\boldsymbol{b} - \boldsymbol{b_A}) dz\, d\boldsymbol{b_A}$$

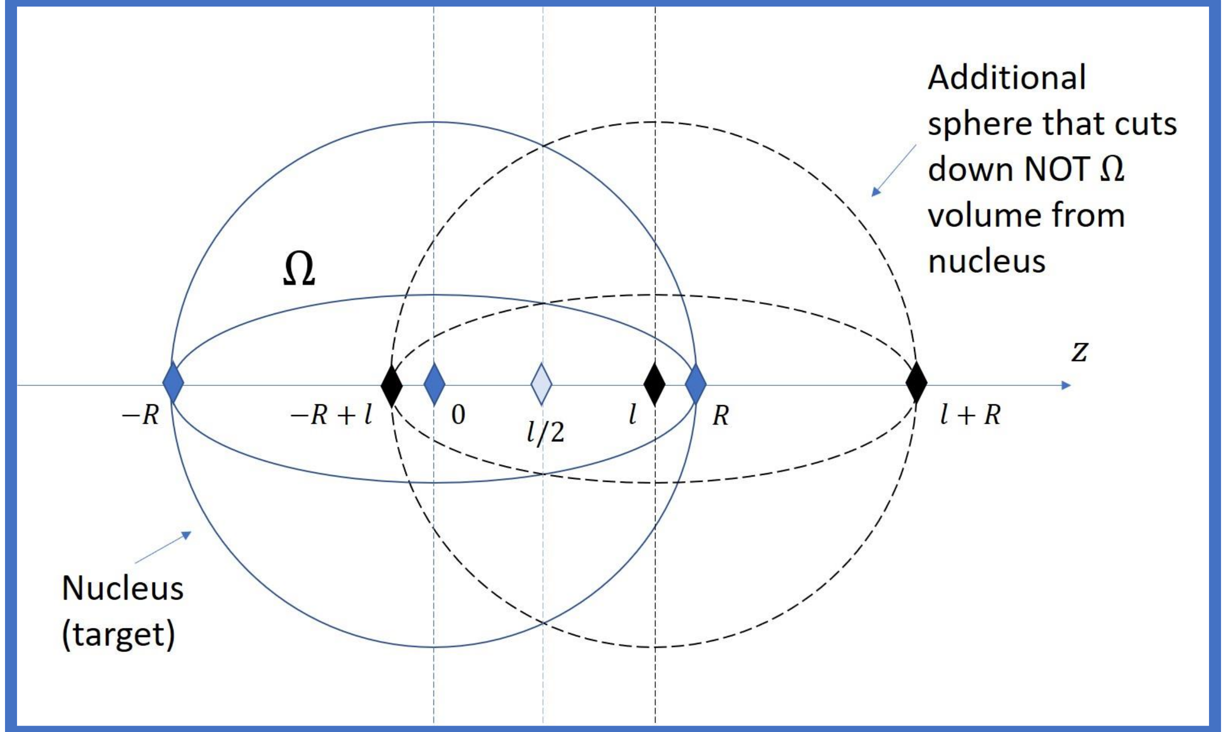
  -thickness function in case of pA-collision (ρ – Woods-Saxon distribution; normalized to unity)

- $$\sigma_{inel}^{NN} T(b) = \int_{\Omega} \rho(z, \boldsymbol{b_A}) \delta(\boldsymbol{b} - \boldsymbol{b_A}) dz\, d\boldsymbol{b_A} \sigma_{inel}^{NN}$$

  - probability to have ONE baryon-baryon inelastic collision when proton and target situated at an impact parameter $\boldsymbol{b}$ relative to each other

- $$P(n, b) = C_A^n \left(\sigma_{inel}^{NN} T(b)\right)^n \left(1 - \sigma_{inel}^{NN} T(b)\right)^{A-n}$$

  - probability to have *n* baryon-baryon inelastic collision when proton and target situated at an impact parameter $\boldsymbol{b}$ relative to each other



Glauber-like approach:

[4] Cheuk-Yin Wong (1994)

- $N_{bin}(\boldsymbol{b}) = \sum_{i=1}^{A} nP(n, \boldsymbol{b})$ - average number on inelastic baryon-baryon collisions at an impact parameter $\boldsymbol{b}$
- $N_{ch}(\boldsymbol{b}) = \sum_{i=1}^{N} N_{ch}^{pp}(v_i) * \Delta N_{bin}(v_i|\boldsymbol{b})$ - average number of multiplicity at an impact parameter $\boldsymbol{b}$!

$$N_{ch}^{pp}(s_{NN}) = a + b * \log(s_{NN}) + c(\log(s_{NN}))^2$$

[5] W.Thomé, K.Eggert, K.Gibini [etc.], (1997)

$\Delta N_{bin}(v_i|\boldsymbol{b})$ - number of binary collisions that happened while proton was decelerating from v_i to v_{i+1}

! In fact, this is an integral that was written in a discrete form for better understanding.

Compare with MC event-generators (full acceptance)

$$N_{\pi^-} = N_{ch}/2;$$

↑

In the Hydrodynamic model of stopping

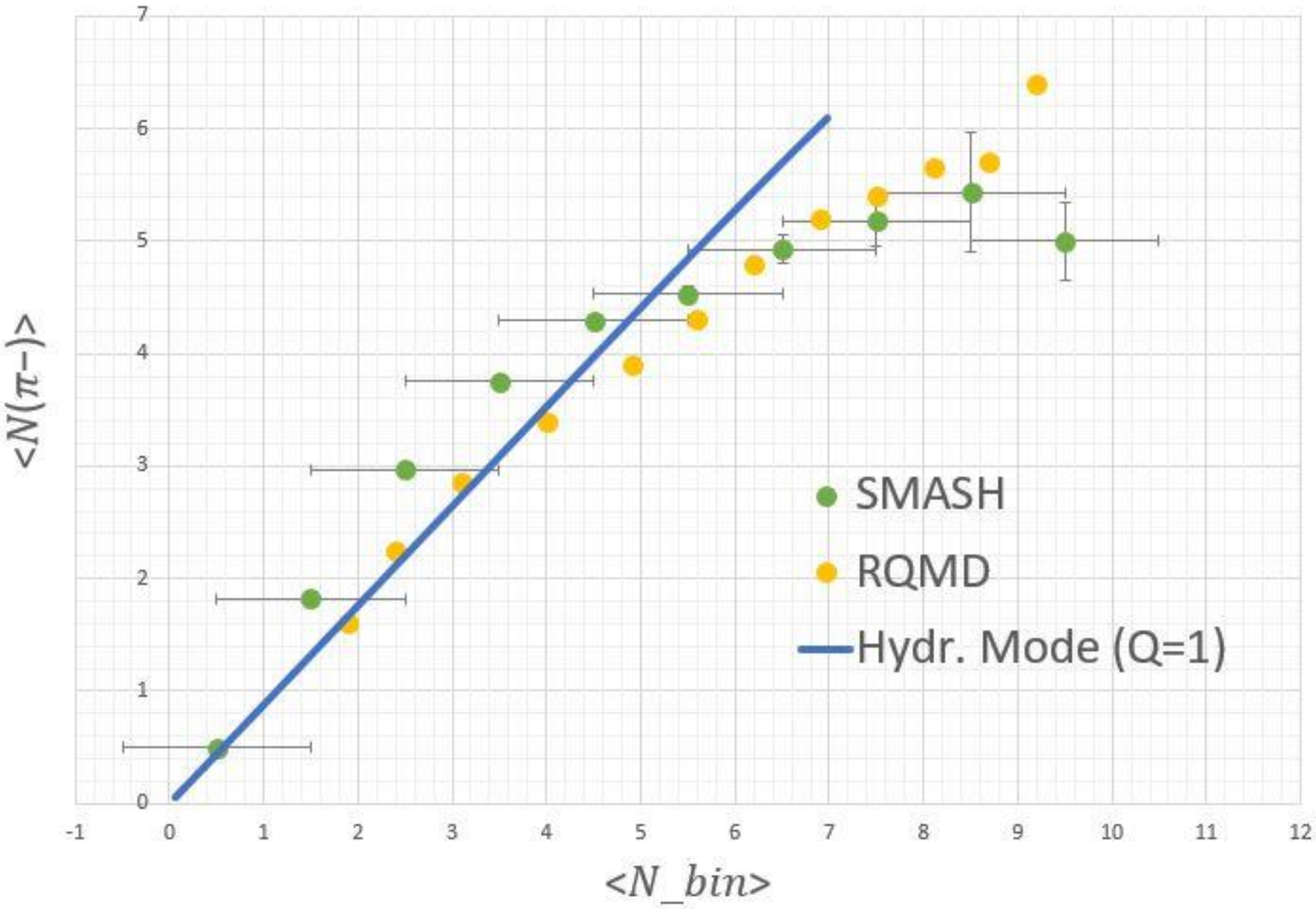


Fig.2 Mean charged particle yields vs. number of binary collisions in RQMD [2], SMASH and in Hydrodynamic model of stopping

p-Au –collision, p_lab = 18 GeV/c

[2] I. Chemakin et al. (1999)

Account of the limited acceptance:

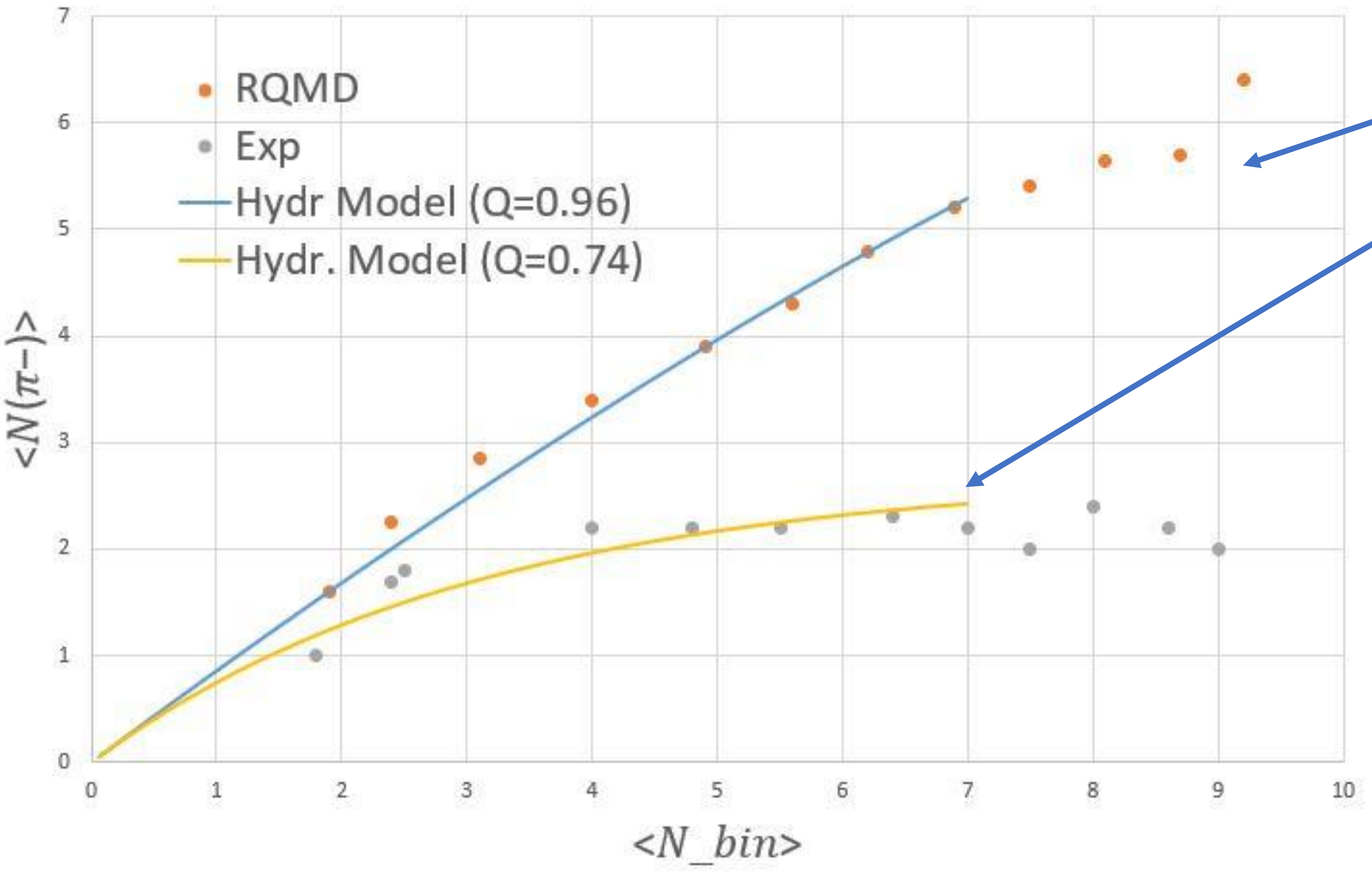
- $$N_{ch} = \sum_{i=1}^{N} N_{ch}^{pp}(v_i) * \Delta N_{bin}(v_i|\boldsymbol{b}) * Q^{\sum_{k=1}^{i} \Delta N_{bin}(v_k|\boldsymbol{b})}$$ - average multiplicity considering acceptance **!**

Q – probability to detect multiplicity that we got from ONE inelastic binary collision. Q^y - probability to detect multiplicity that we got from y inelastic binary collisions.

$\Delta N_{bin}(v_i|\boldsymbol{b})$ - number of binary collisions that happened while proton was decelerating from v_k to v_{k+1}

! In fact, this is an integral that was written in a discrete form for better understanding.

Account of the limited acceptance:



Full acceptance

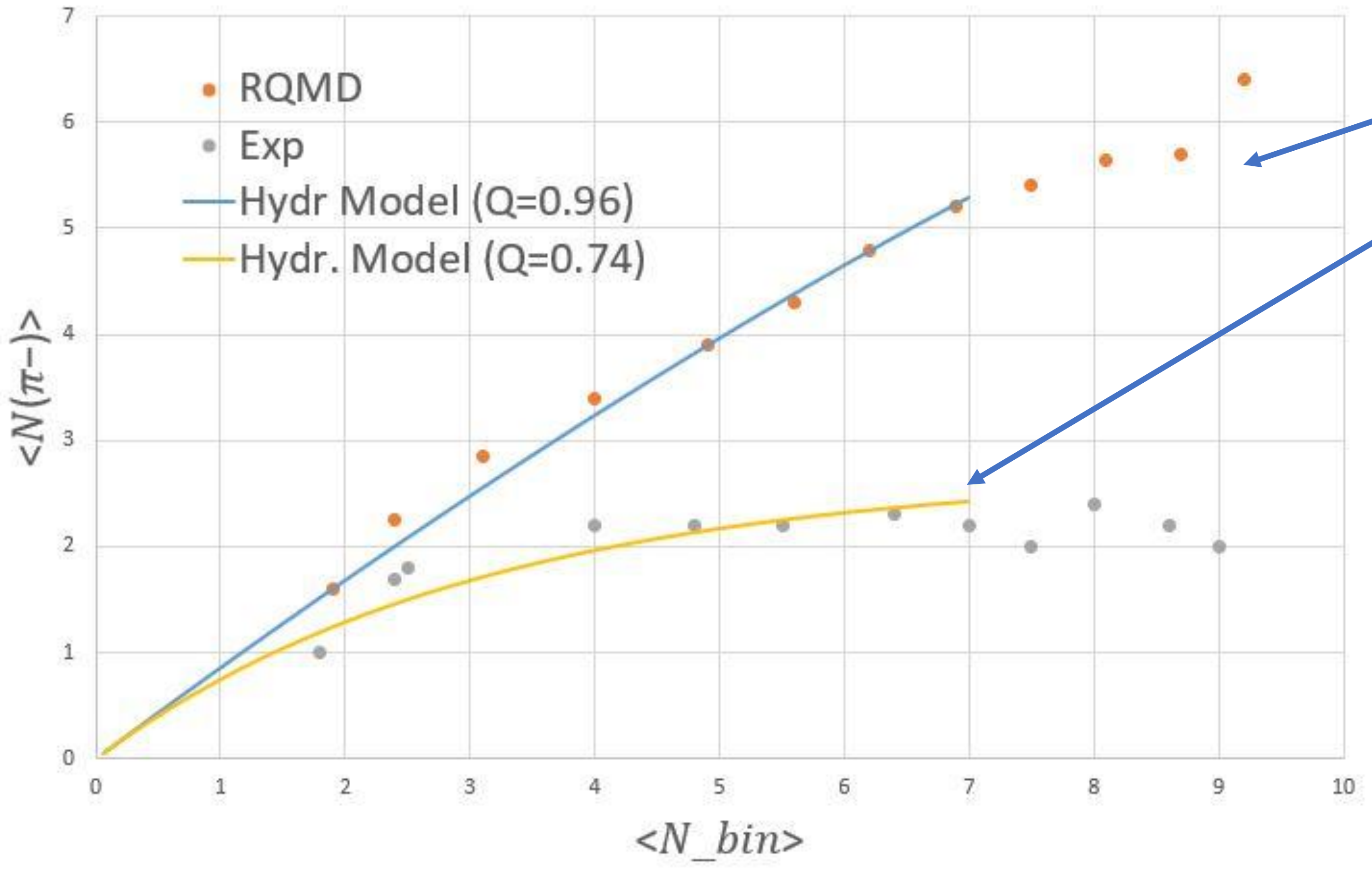
Limited acceptance

Fig.2 Mean charged particle yields vs. number of binary collisions in RQMD [2], experiment at BNL and in Hydrodynamic model of stopping considering acceptance

p-Au – collision, p_lab = 18 GeV/c

[2] I. Chemakin et al. (1999)

Account of the limited acceptance:



Full acceptance

Limited acceptance

Data + RQMD [2]

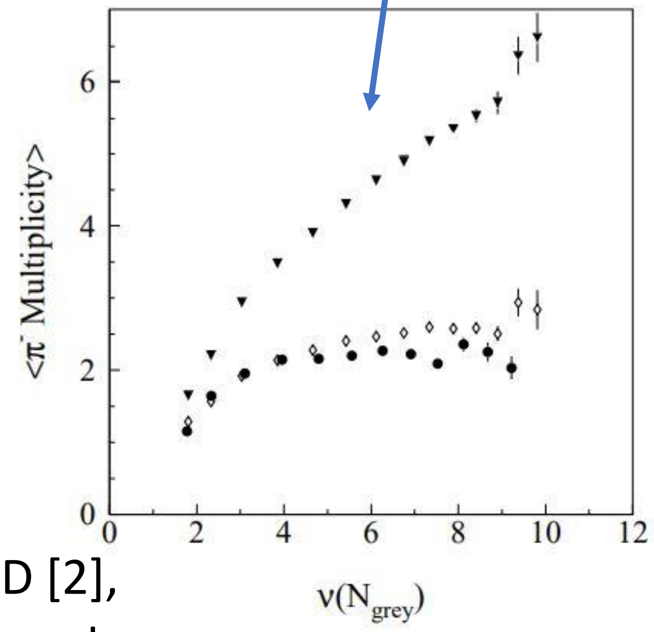


Fig.2 Mean charged particle yields vs. number of binary collisions in RQMD [2], experiment at BNL and in Hydrodynamic model of stopping considering acceptance

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Conclusion

- A new hydrodynamic model of nucleon stopping that describes the deceleration of a proton in a nucleus and based on hydrodynamics is proposed. No fitting coefficients are required.
- The linear dependences for the p-A collisions were obtained. This is in line with experiment on p-Au collisions at p_lab = 18 GeV/c in the first approximation. Similar dependence is demonstrated by the MC models RQMD an d SMASH.
- The non-linear behavior of multiplicity vs. number of binary collisions -description is found to be a result of limited acceptance of the experimental data.
- Results of these studies of nucleon stopping are important for the future analysis of centrality selection in p-A and A-A collisions at NICA experiments.

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Back Up

SMASH - **S**imulating **M**any **A**ccelerated **S**trongly-Interacting **H**adrons

Based on the relativistic Boltzmann equation :

$$p^\mu \partial_\mu f_i(x,p) + m_i F^\alpha \partial^p_\alpha f_i(x,p) = C^i_{coll}$$

At each step along the time axis, for each particle, its trajectory is calculated using the Boltzmann equation.

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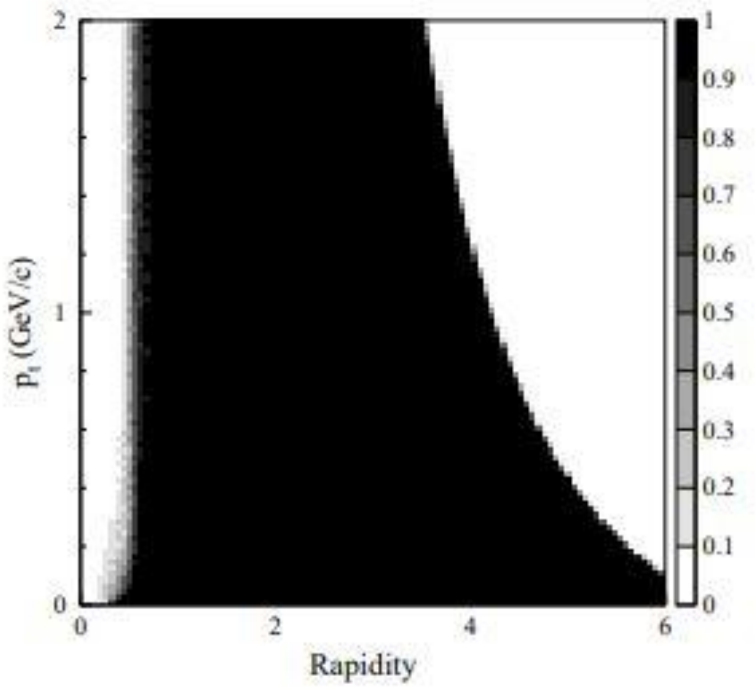

Acceptance in BNL experiment

[2] I. Chemakin et al. (1999)